# Triple-barrel Graft as a Novel Strategy to Preserve Supra-aortic Branches in Arch-TEVAR Procedures: Clinical Study and Systematic Review

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**Objective:** To report our early experience with total endovascular repair of aortic-arch aneurysm using double chimney-grafts and present a literature overview.
**Patients and methods:** The double chimney-graft technique was performed in six male patients with contained ruptured aneurysm, dissecting aneurysm, pseudoaneurysm, penetrating aortic ulcer and proximal endoleak after TEVAR. Furthermore, a systematic electronic health database search of available articles was conducted according to PRISMA Guidelines.
**Results:** In all cases, all supra-aortic vessels had to be covered with aortic stent-graft to receive a sufficient landing and sealing zone. Chimney-grafts were introduced to the ascending aorta slightly deeper than the thoracic stent-grafts through the cut-down exposure of the common carotid arteries. We deployed aortic stent-grafts and self-expandable chimney-grafts simultaneously and successfully. The patient with contained ruptured aneurysm died due to cardiopulmonary failure on day 19, the others survived. We detected two 'gutter' endoleaks. As a result of literature search, 12 articles met the inclusion criteria. Two articles described the double-chimney technique.
**Conclusions:** The use of double chimney-grafts is possible in high-risk patients where the proximal landing zone of endograft would be in zone 0. The available data is still limited. The long-term follow-up remains to be evaluated with the increased number of patients treated.

Article history: Received 26 May 2012, Accepted 30 September 2012, Available online 2 November 2012
**Keywords:** Aorta, Arch aneurysm, Chimney-graft, Endovascular repair, Stent-graft, TEVAR (total endovascular techniques)

Open surgical treatment of pathologies (aneurysms or dissection) of the aortic arch and the proximal descending aorta (DA) with or without involvement of supra-aortic arteries, is connected to high mortality and morbidity rates in patients considered high-risk for open aortic-arch surgery and many are turned down for treatment.[1,2] Based on this, alternative techniques such as hybrid or total endovascular repair are applied to extend the landing zone for the stent-graft. These may include an extra-anatomical bypass such as carotid-to-carotid (RCCA—LCCA) or left carotid-to-subclavian (LCCA—LSA) bypass in cases of landing zone 2 or 1. In cases of landing zone 0 one needs a sternotomy if a hybrid procedure without requiring cardiopulmonary bypass is chosen.[3] Although associated with lower mortality rates than open repair,[4—9] it is still reported with higher morbidity and mortality rates compared to a complete endovascular procedure.[6,10—12]

The total endovascular techniques (TEVAR) eliminate sternotomy and thus further reduce the surgical trauma, resulting in lower morbidity and mortality rates.[13,14] The introduction of fenestrated and side-branched endografts made it feasible to apply an endovascular technique in patients with a proximal landing zone in 0—1. Yet, these endografts are still under development and are not readily available, especially in the emergency situations due to technical and logistic reasons. Additionally, they are costly. Although some groups use the *in situ* graft fenestrations with an *in situ* laser technique or home-made endografts, this technique is complex and not widely available.[15,16]

The recently developed chimney-graft technique was first described by Greenberg[17] and was later performed in different groups for visceral and supra-aortic branches,[18—24] known as the double-barrel technique.[25,26] This procedure may be an alternative to open or hybrid arch surgery or in emergencies after intended or accidental coverage of an important branch.[24]

The aim of the present study is to evaluate the current available data regarding chimney-graft technique of supra-aortic branches; moreover, we present our experience with the triple-barrel technique in patients, who underwent implantation of double chimney-grafts in the arch.

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http://dx.doi.org/10.1016/j.ejvs.2012.09.023

## METHODS

### *Search and analysis of data*

A systematic electronic health database search was performed in May 2012 according to the PRISMA Guidelines (www.prisma-statement.org) using Medline, Embase, Ovid, Web of Science, the Cochrane Database of Systematic Reviews as well as the Cochrane Database of Abstracts of Reviews of Effectiveness on all available articles using the following keywords: 'chimney', 'chimney-graft', 'snorkel', 'sandwich', 'periscope', 'aortic arch aneurysm', 'double-barrel', 'triple-barrel', 'stent', 'graft'. The search was restricted to publications, reporting at least one patient treated with chimney-graft preserving one or more supra-aortic branches (left subclavian (LSA), left common carotid (LCCA) and innominate arteries (IA)). Moreover, the references of all included articles were examined for further relevant series. The articles that did not report technical success, mortality and morbidity were eliminated from further analysis. All selected full-text articles were in English and were independently evaluated by two authors (RS and MG). From the attained articles the overall patient data were obtained. The total number of procedures and the number of chimney-grafts were analysed. Finally, the post-operative follow-up, including mortality and morbidity rates, was evaluated.

## Personal series

During February 2010 through May 2012 the chimney-graft technique was used in six male patients (73 years in median; range 49–80), merging the double chimney-grafts with an aortic stent-graft in the thoracic aorta. The proximal landing zone of the stent-graft was classified using Criado's anatomical landing zone map.[3] In all cases the IA, LCCA and LSA had to be covered to create a sufficient landing zone (zone 0). The indications for the patients' treatment were contained ruptured aneurysm ($n = 1$), dissection ($n = 1$), proximal endoleaks in zone 2 after previous TEVAR ($n = 2$), pseudoaneurysm ($n = 1$) and penetrating aortic ulcer (PAU) ($n = 1$). Each case had been discussed in an interdisciplinary board (vascular/endovascular and cardiac surgeons, anaesthesiologist) pre-operatively. Based on the individual situation, such as a history of multiple sternotomies and/or multiple co-morbidities, sternotomy had been rejected by the cardiac surgeons and the endovascular approach was indicated. Since they had an inadequate proximal neck for conventional TEVAR, the double chimney-graft technique was chosen as an option. All patients were informed about the risks and had given a written consent form to endovascular repair. The patients were pre-operatively classified by the American Society of Anaesthesiologists (ASA) classification[27] and underwent risk evaluation according to the European System for Cardiac Operative Risk Evaluation (EuroSCORE) guidelines.[28] All patients were taking either Aspirin 100 mg/day or Clopidogrel 75 mg/day. Two patients were additionally taking Phenprocoumon. Individual risk factors and co-morbidities are shown in Table 1.

All patients underwent pre-operative contrast-enhanced computed tomography angiography (CTA) from the neck to the groins, performed with a 2 × 128-slice dual source CT scanner (Somatom Definition Flash, Siemens Medical Systems, Erlangen, Germany).

The first, haemodynamically stable, patient presented with chest pain and CT scan revealed a contained rupture of arch/proximal descending aorta aneurysm. He was on dialysis and had multiple co-morbidities.

The second patient had a prior open repair of the ascending aorta (acute Stanford-A dissection). Four years later he had a progressing asymptomatic aneurysm of the dissected descending aorta with progression of old dissection membrane into the proximal IA and further to the right subclavian artery (RSA).

The third patient had a previous history of Stanford-A dissection due to Marfan syndrome, followed by open repair of the ascending aorta. Furthermore, he had undergone TEVAR for aneurysmal formation of the descending aorta due to chronic dissection, and another replacement of the ascending aorta due to insufficiency of the prosthetic anastomosis distally with a consecutive pseudoaneurysm. The patient had an asymptomatic progressive aneurysm of the aortic arch with concomitant development of type Ia endoleak.

The fourth patient had a prior coronary artery bypass surgery (CABG) followed by multiple resternotomies and plastic coverage of sternal wound with pectoral muscle due to wound infections and osteomyelitis. Two years later he presented with chest pain and infected sternal fistula with bloody secretion. The CT revealed a pseudoaneurysm of aortic arch from the cannulation point during the CABG connected to the sternal fistula.

The fifth patient had a previous history of TEVAR for aneurysm of the descending aorta. In addition, he had undergone visceral hybrid repair due to type Ib endoleak. Three years later, the patient had an asymptomatic progressing aneurysm of aortic arch with concomitant development of type Ia endoleak.

The sixth patient with multiple co-morbidities was admitted due to general weakness and shortness of breath with huskiness. The CT revealed a PAU of proximal descending aorta with concomitant development of a pseudoaneurysm as well as pleural and marginal pericardial effusion (Fig. 1).

**Table 1.** Patients' co-morbidities.

| Patient no. | Hypertension | Myocardial infarction | CHD | COPD | PAD | Smoker | Previous aortic/cardiac surgeries |
|---|---|---|---|---|---|---|---|
| 1 | Yes | Yes | Yes | Yes | No | Past | No |
| 2 | Yes | No | No | No | No | Past | Thoracic |
| 3 | Yes | Yes | Yes | Yes | Yes | Past | Thoracic |
| 4 | Yes | Yes | Yes | No | No | Past | Cardiac |
| 5 | No | No | No | No | Yes | Past | Thoracic and abdominal |
| 6 | Yes | No | No | Yes | Yes | Past | No |

CHD: coronary heart disease, COPD: chronic obstructive lung disease, PAD: peripheral arterial disease.

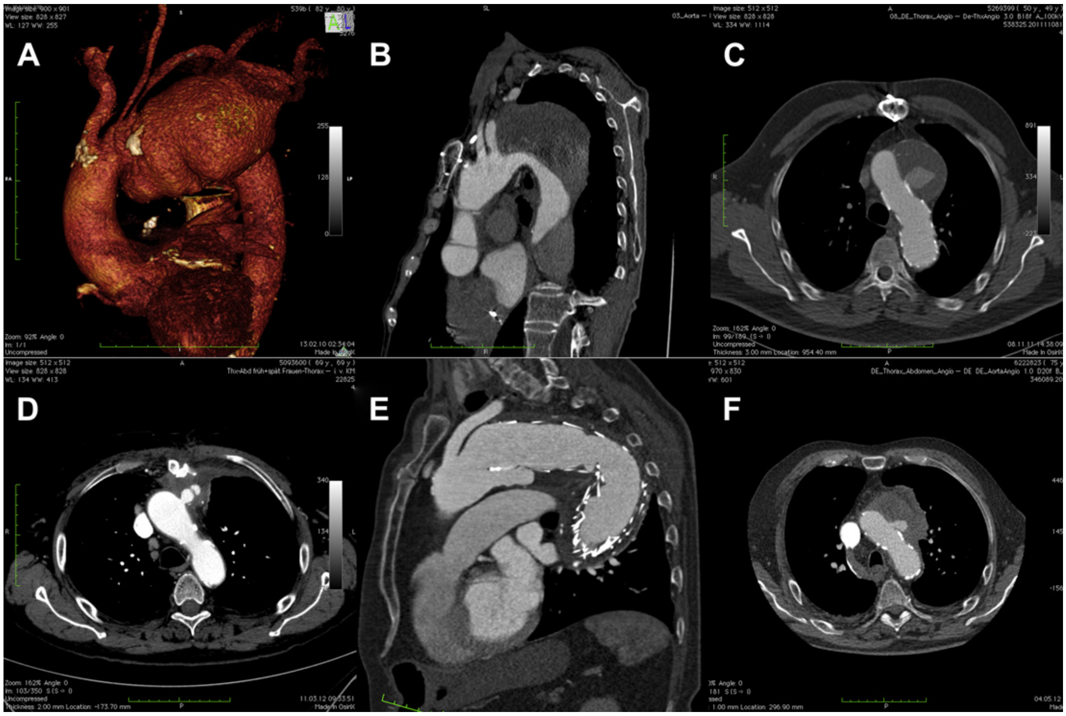


**Figure 1.** 2- and 3-dimensional CTA-imaging of thoracic aorta demonstrating the pathology of aortic arch/descending aorta. (A): contained ruptured aneurysm, (B): dissecting aortic aneurysm, (C) and (E): proximal endoleak after TEVAR, (D): pseudoaneurysm, (F): PAU. A-F corresponds to patients 1—6.

The overall patients' data are demonstrated in Table 2.

## RESULTS

### *Personal series*

All patients underwent early elective surgery under general anaesthesia. Through neck incisions the CCAs were exposed and punctured. Then, in order to reduce the risk for 'gutter' endoleak, the 15—20% oversized Gore Viabahn® or Excluder® (W.L. Gore & Associates, Inc., Flagstaff, AZ, USA) leg was inserted into the ascending aorta. Similarly, a 20—30% oversized Gore Conformable Thoracic Aorta Graft (CTAG®) (W.L. Gore & Associates) was simultaneously introduced. The chimneys were introduced slightly deeper into the ascending aorta than the CTAG®, with an overlapping length of 5 cm. Next, rapid left-ventricular (LV) pacing with heart beat rate of 180 beats/min and reduction of systolic blood pressure ($<$60 mmHg) was applied to prevent the bloodstream-induced dislocation of the grafts. The CTAG® was then deployed, directly followed by the deployment of the chimney-grafts, which was completed by balloon modelling. A completion angiogram was performed and, when needed, identified endoleaks were corrected by another balloon modelling. Post-operative CTA was performed within the next 7 days in all cases. The overall data associated with the surgery are presented in Table 3.

The LSA was preserved in second, third and fifth cases, but not in others due to individual anatomical characteristics and only coverage of a short segment of the thoracic aorta with the stent-graft and expected low risk of SCI. Preoperative CT revealed a filiform stenosis of LSA and occlusion of the left vertebral artery (LVA) in the first case and a dominant right vertebral and hypoplastic LVA in the fourth and sixth cases. In the second patient the diameter of the innominate artery was too large for a sealing of the available applicable stent-grafts as a chimney-graft and therefore we performed a transposition of the LSA and RCCA—RSA bypass during the chimney-procedure, allowing the chimney-graft to be inserted into the RCCA, covering the orifice of the RSA. Patients 3 and 5 had a pre-existing

**Table 2.** Patients' overall characteristics.

| Patient no. | Age | Gender | ASA | Euro SCORE | Main diagnosis | Max. aneurysm diameter |
|---|---|---|---|---|---|---|
| 1 | 80 | Male | ASA 4 | 11 | Contained rupture of descending aortic aneurysm | 90 mm |
| 2 | 70 | Male | ASA 3 | 8 | Dissecting aortic aneurysm | 75 mm |
| 3 | 49 | Male | ASA 3 | 10 | Endoleak type Ia | 73 mm |
| 4 | 69 | Male | ASA 3 | 11 | Pseudoaneurysm | 26 mm |
| 5 | 77 | Male | ASA 3 | 10 | Endoleak type Ia | 61 mm |
| 6 | 76 | Male | ASA 4 | 13 | PaU | 72 mm |

**Table 3.** Stent-graft characteristics.

| Patient no. | Aortic stent-graft | Landing zone | Branches assessed | CG type | CG model | Supplementary procedure |
|---|---|---|---|---|---|---|
| 1 | Gore CTAG® Excluder TGE 45 × 45 × 200 mm, TAG 45 × 200 mm | Zone 0 | IA, LCCA | Covered | Gore Viabahn® 13 × 100 mm, 8 × 100 mm | None |
| 2 | Gore CTAG® Excluder TGE 40 × 40 × 200 mm, TAG 40 × 200 mm | Zone 0 | IA, LCCA | Covered | Gore Viabahn® 13 × 100 mm, 10 × 100 mm | Transposition of LSA<br>RCCA-RSA bypass |
| 3 | Gore CTAG® Excluder TGE 37 × 37 × 150 mm | Zone 0 | IA, LCCA | Covered | Gore Viabahn® 10 × 100 mm, BARD Fluency® 10 × 40 mm, 2 × Excluder® PXC 161010 | LCCA-LSA Bypass |
| 4 | Gore CTAG® Excluder TGE 45 × 45 × 150 mm, TGE 45 × 45 × 100 mm | Zone 0 | IA, LCCA | Covered | Gore Viabahn® 10 × 100 mm, 2 × Excluder® PXC 161407 | RCCA-LCCA bypass |
| 5 | Gore CTAG® Excluder TGE 45 × 45 × 200 mm | Zone 0 | IA, LCCA | Covered | Gore Viabahn® 13 × 100 mm, Excluder® PXC 161000 | LCCA-LSA bypass |
| 6 | Gore CTAG® Excluder TGE 37 × 37 × 200 mm | Zone 0 | IA, LCCA | Covered | Gore Viabahn® 10 × 100 mm, Excluder® PXC 201000 | None |

IA: innominate artery, LCCA: left common carotid artery, RCCA: right common carotid artery, LSA: left subclavian artery, RSA: right subclavian artery, CG: chimney-graft, CTAG: Conformable Thoracic Aorta Graft.

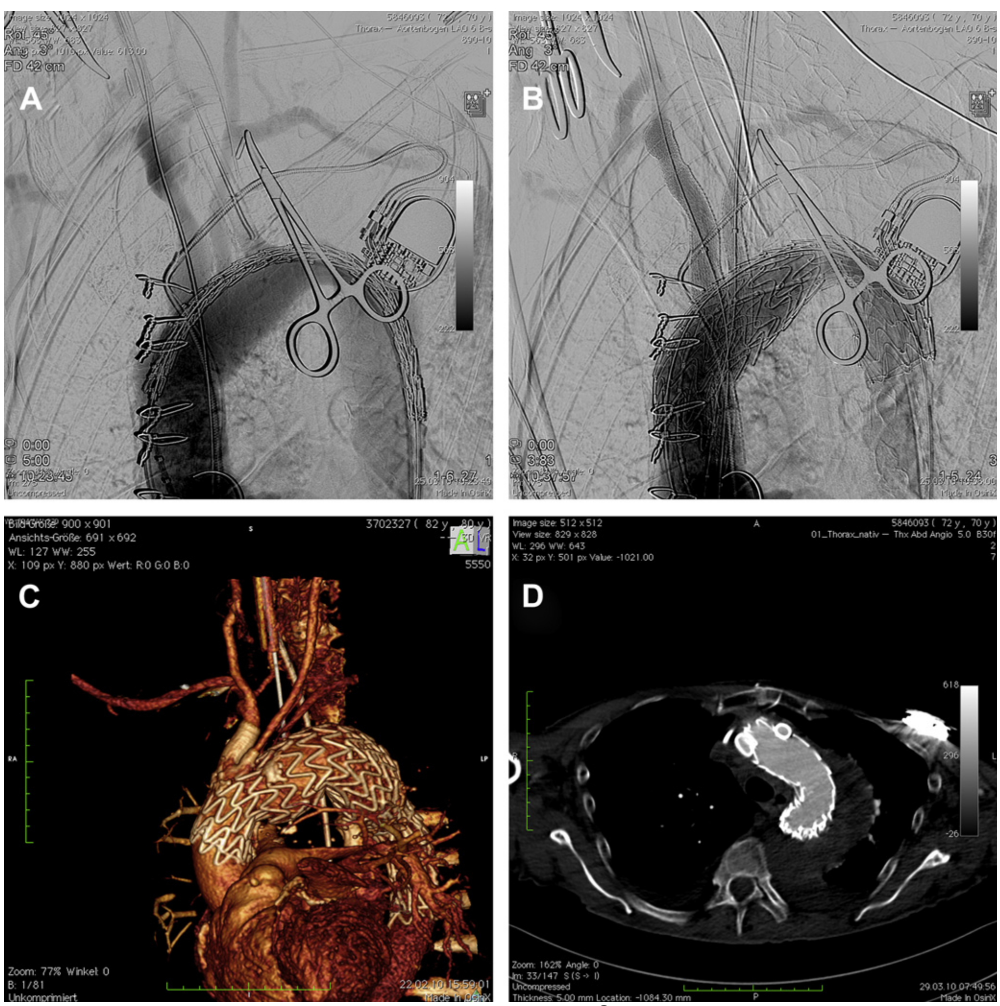


**Figure 2.** (A) and (B): intraoperative angiogram showing deployment of CTAG® and chimney-grafts (C) and (D): postoperative 3- and 2-dimensional CTA-scan of excluded aneurysm.

**Table 4.** Overall chimney-graft characteristics.

| Author | No. Of patients | Supra-aortic branches/ CG placement | | | Total no. of CG |
|---|---|---|---|---|---|
| | | IA | LCCA | LSA | |
| Larzon et al. | 2 | 0 | 2 | 0 | 2 |
| Hiramoto et al. | 1 | 0 | 1 | 0 | 1 |
| Criado | 8 | 0 | 6 | 2 | 8 |
| Ohrlander et al. | 4 | 1 | 2 | 1 | 4 |
| Baldwin et al. | 7 | 3 | 3 | 1 | 7 |
| Sugiura et al. | 11 | 3 | 7 | 1 | 11 |
| Feng et al. | 1 | 1 | 1 | 0 | 2 |
| Gehringhoff et al. | 9 | 0 | 3 | 6 | 9 |
| Cires et al. | 9 | 2 | 2 | 5 | 9 |
| Shu et al. | 8 | 0 | 8 | 0 | 8 |
| Yoshida et al. | 2 | 2 | 2 | 0 | 4 |
| Vallejo et al. | 8 | 3 | 5 | 0 | 8 |
| | 70 | 15 | 42 | 16 | 73 |

IA: innominate artery, LCCA: left common carotid artery, LSA: left subclavian artery, CG: chimney-graft.

LCCA—LSA bypass, which had been obtained for the primary TEVAR procedure.

We used Gore CTAG® stent-grafts and Viabahn® or Excluder® as chimney-grafts simultaneously and successfully in all cases. They all need larger sheaths, which is why we introduced the chimney-grafts through neck incisions and not percutaneously. In patient number 4 we detected an infolding Viabahn® of the LCCA at the end of the procedure. It appeared most probably during the removal of all devices (pulling the distal part of the Viabahn® by the proximal cone), so that the Viabahn® kinked towards the descending aorta. Therefore, it was impossible to reline it with another stent and we performed an RCCA—LCCA bypass.

The mean operation time was 136 min (range 106—179). The completion angiogram showed no endoleak and a patent IA, left and right common and internal carotid arteries, as well as subclavian arteries, except for the cases where the flow into the left subclavian artery was not preserved.

The post-operative CT revealed patent chimney-grafts (except for case 4 with infolded Viabahn®) and supra-aortic arteries. There was one case of retrograde endoleak from the LCCA in patient number 3, which is why we introduced an extra BARD Fluency® chimney-graft (C. R. BARD Inc., Murray Hill, NJ, USA) further cranial into the LCCA 7 days after the initial procedure, eliminating the endoleak. The fourth patient had a proximal type Ia endoleak, which was completely eliminated 2 days later by deploying another aortic stent-graft further proximal in the ascending aorta and additional balloon modelling of all stent-grafts.

**Table 5.** Overall results of currently available articles on chimney-graft technique preserving supra-aortic branches.

| Article | Pat. No. | Study, type | Age | Gender (M/F) | Diagnosis | Supplementary procedures |
|---|---|---|---|---|---|---|
| Personal series | 6 | Chimney | 73 (49—80) | 6M | Arch Aneurysm, TAA, SG Migration + EL, Pseudoaneurysm, PaU | RCCA-LCCA, LCCA-LSA, RCCA-RSA |
| Ohrlander et al. | 4 | Mixed Chimney | N/D | N/D | Type B Dissection, Arch Aneurysm, TAA | RCCA-LCCA, LCCA-LSA |
| Feng et al. | 1 | Chimney | 36 | F | Type 1 EL | Coiling LSA |
| Gehringhoff et al. | 9 | Chimney | 57 (39—76) | 7M/2F | Type B Dissection, SG Migration + EL, PaU, Mobile Arch Thrombus, Arch Aneurysm | LCCA-LSA |
| Cires et al. | 9 | Chimney | 64 (35—85) | 6M/3F | Traumatic Transection, TAA, TAAA, Type B Dissection, Pseudoaneurysm, Aortotracheal Fistula | RCCA-LCCA, LCCA-LSA |
| Larzon et al. | 2 | Chimney | 73 (68—78) | 2M | Type 1 EL, Arch Aneurysm | LCCA-LSA |
| Shu et al. | 8 | Chimney | 49 (29—75) | 7M/1F | Non-A—non-B, Dissection | None |
| Sugiura et al. | 11 | Chimney | N/D | N/D | Type B Dissection, Arch Aneurysm, Descending Aneurysm, Traumatic Transection, Aortoesophageal Fistula | RCCA-LCCA |
| Vallejo et al. | 8 | Mixed | N/D | N/D | N/D | N/D |
| Criado | 8 | Chimney | N/D | N/D | N/D | None |
| Yoshida et al. | 2 | Chimney | 76 (72—82) | M/F | Arch/Descending Aneurysm | LCCA-LSA |
| Hiramoto et al. | 1 | Chimney | 70 | M | Descending Aneurysm | None |
| Baldwin et al. | 7 | Chimney | 69.7 (42—78) | 4M/3F | Type B Dissection, PaU, Arch Aneurysm, Traumatic Disruption | RCCA-LCCA, LCCA-LSA |

TAA: thoracic aortic aneurysm, TAAA: thoracoabdominal aortic aneurysm, SG: stent-graft, CG: chimney-graft, EL: endoleak, RCCA: right common carotid artery, LCCA: left common carotid artery, RSA: right subclavian artery, LSA: left subclavian artery, TAG: Thoracic Aorta Graft, N/D: not defined, FU: follow-up, Diff.: different.

The mean in-hospital stay was 23 days (range 13—30). The patient number 1 had a complicated post-operative course. He suffered from prolonged artificial ventilation with tracheal cannulation as well as an inadequate neurological vigilance. The CT showed no signs of fresh cerebral ischaemia or intracranial haemorrhage. The chimney-grafts and the cranial arteries were patent. Ultimately, the patient died on day 19 due to cardiopulmonary failure.

During the follow-up period (2.5 months in median; range 0.5—6.5), the patient number 2 died 6.5 months after the surgery because of a ruptured iliac or infrarenal aortic aneurysm in another hospital.

CT scan of patient number 3 after 6 months revealed a retrograde endoleak from the IA. Therefore, we introduced an extra Excluder® leg further cranial into the IA via the right-sided axillar route. Another CT scan after the procedure demonstrated a proximal 'low-flow' gutter endoleak. We therefore decided to perform the next CT scan in 6 months.

The patient number 5 suffered prolonged artificial ventilation with tracheal cannulation. He developed post-operative haematoma at the access side of the neck, which was surgically revised. After successful weaning he was discharged on the 28th day. He then suffered SCI of unknown genesis 3 weeks later with paraparesis of lower extremities. The CT scan showed patent chimney-grafts and cranial arteries with no sign of endoleak.

We detected another proximal 'low-flow' gutter endoleak in the last patient. The patient will receive his next CT scan in 3 months (Fig. 2).

## Literature review

In total, 12 articles met the inclusion criteria and were thoroughly examined.[20,23—26,29—35] Out of those only two articles described the double-chimney technique[30,35] and the rest — a single chimney-graft of IA, LCCA or LSA respectively (Table 4).

It was not possible to evaluate the age, gender or main diagnosis in all acquired studies, as in some of the retrieved studies there was a mixed patient collective of both thoracic and visceral arteries.[24] In others, chimney-grafts were compared with open or hybrid repair.[24,34] Likewise, there was inhomogeneity with respect to revascularisation of the LSA prior to placing the endografts, and different methods such as transposition of LSA or left carotid-to-subclavian bypass were performed.[23—25,29,31] However, all patients underwent a carotid-to-carotid bypass before the aortic stent-graft was placed in zone 0 and the chimney-graft in the IA.[24,25,29,33] Various aortic stent-grafts (Zenith®, Gore®, Talent®, etc.) were used for the thoracic aorta and numerous variable bare-stents or covered stents were selected for chimney-grafts.[20,23—26,29—34]

| Thoracic SG | CG | Technical success | Early mortality | Early morbidity | EL | CG patency | FU (mo) |
|---|---|---|---|---|---|---|---|
| Gore C-TAG | Viabahn, Excluder | 83.5% | 1 | Paraparesis: 1 | Type I: 2, Type II: 1 | 100% | 2.5 |
| Zenith, Gore TAG | Luminex, Advanta, Zenith TFLE | 100% | 0 | Stroke: 1 | Type I: 1, Type II: 1 | 100% | 2 |
| Relay | SINUS | 100% | 0 | 0 | 0 | 100% | 12 |
| TX2, Valiant | Advanta, Genesis, Smart and Fluency | 88.9% | 1 | 0 | Type I: 1 | 100% | 15 |
| Gore TAG, Talent | Bare-stents | 88.9% | 1 | Stroke: 1, MI: 1 | Type I: 1 | 100% | 5 |
| Gore TAG | Symphony, Zilver, Palmaz Genesis | 100% | 0 | 0 | Type II: 2 | 100% | 0.87 |
| Hercules, Relay, Zenith | Fluency, Passenger | 100% | 0 | 0 | Type II: 2 | 100% | 11.4 |
| Cook, Gore TAG | Diff. | 100% | 1 | Paraplegia: 1, Stroke: 1, Iliac haemorrhage: 1 | Type I: 2 | 100% | 20.1 |
| Gore TAG, Talent, Valiant | Medtronic AneuRx, Genesis Palmaz, Express | 100% | 1 | Stroke: 1 | Type I/II: 1 | 100% | N/D |
| Talent | Bare-stents | 100% | 0 | 0 | 0 | 100% | N/D |
| ProForm | Viabahn | 100% | 0 | 0 | 0 | 100% | 13.5 |
| Gore TAG | Fluency | 100% | 0 | 0 | 0 | 100% | 1 |
| Gore TAG | Fluency, Luminex, Wallstent, Zilver, Biliary Express | 100% | 0 | Stroke: 1 | Type II: 1 | 100% | N/D |

Combining acquired data with our own results there were five deaths during the post-operative 30-day period, resulting in a 30-day mortality rate of 6.5%.[29,31,33,34] The technical success was 97% (95% CI, 93.5—100%), but during follow-up there were 15 combined type I/II endoleaks (19.7%).[23—25,29,31—34] In total, there were five strokes, two cases of paraplegia and one case each of myocardial infarction and iliac haemorrhage (11.8%).[24,29,33,34]

The patency of the chimney-grafts during a mean follow-up of 8.3 months, described in 9 studies, was 100%[23,24,26,29—33,35] (Table 5).

## DISCUSSION

The chimney-graft approach presents an alternative for the treatment of proximal aortic pathologies. Introduced during accidental coverage with aortic stent-graft,[17] it was then applied for both visceral and supra-aortic arteries, showing encouraging results with a high technical success and satisfactory chimney-graft patency.[18,19,21,22,24] However, the application in supra-aortic arteries is still limited.

The chimney-graft technique in the aortic arch is reported to be associated with low mortality rates.[29,31,33,34] The main reason for mortality was predominantly a lethal stroke,[29,33] followed by cardiac insufficiency.[31] Our experience demonstrates that such high-risk patients presenting urgently with aortic-arch pathology and severe co-morbidities do not fare too well in the short-term follow-up.

The main concern using the chimney technique is the appearance of proximal endoleak due to an inadequate seal between chimney-grafts, aortic stent-graft and aortic wall. Previous reports describe the displacement of the main endograft by the chimney-graft during its deployment, resulting in the development of the ‘gutters’ and leading to an endoleak.[24] For this reason, performing an intraoperative ‘kissing balloon’ procedure during a visceral chimney-graft technique was suggested, if a type I endoleak is detected on the completion angiogram.[19,36] Another alternative was to routinely reinforce the covered stents with bare-stents and vice versa.[19]

Furthermore, the deployment of slightly oversized aortic stent-grafts may reduce the risk for ‘gutter’ endoleak and for compression of the chimney-graft. In order to provide good sealing, we oversized the main aortic stent-graft by 20—30% up to the largest stent-graft possible. There are no data available in the literature on how much oversizing is needed, but Yoshida also oversized the stent-grafts by 20%.[35]

Ohrlander and co-workers reported that the ‘gutters’ increase with the size of the chimney-graft.[24] Therefore, the proper selection of the chimneys and the correct diameter of all grafts seem to be important. We selected the aortic stent-grafts and the chimneys from Gore using CTAG® and the Viabahn® or Excluder® depending on the size needed. These stent-grafts have an equally good conformability and flexibility and could be deployed without being compressed.

The length of the chimney-grafts and consequently the overlapping of all grafts play an important role in the development of a ‘gutter’ endoleak. The blood flow in the ‘gutter’ is slow due to its narrowness, so that the chance of its sealing is proportional to the length of the blood flow. Thus, the longer the length of the gutter is, the higher seems to be the chance for the blood to clot. Lachat suggested that an overlapping of the chimney-grafts with the aortic stent-graft should be over 2—3 cm[37] and Kolvenbach recommended an overlapping of at least 7 cm.[38] Still, due to the short distance between the coronary and supra-aortic arteries, we inserted the chimney-grafts with a 5-cm overlap of the aortic stent-graft to avoid significant perfusion of the ‘gutter’. However, a safe and precise length of the overlapping needed requires further studies.

The publications do not allow any firm conclusions regarding the use of bare or covered chimney-grafts with respect to neurological events or technical difficulties. The advantage of bare-stents is the possibility of placing these percutaneously without need of cervical incisions and clamping of the carotid arteries. The drawback is though, that there may be a higher rate of endoleak as the bare stent does not seal but only provides a ‘road’ for the blood into the desired branch. However, we used covered stent-grafts from the same company and out of the same material as the aortic stent-graft in the case of double-chimneys of supra-aortic vessels due to its flexibility, where the risk of chimney-stenosis and endoleak could be reduced.

## CONCLUSIONS

The triple-barrel chimney technique to supply blood flow to the supra-aortic vessels has been performed successfully in a small number of high-risk emergently presented patients with a hostile operative field. It may be used in patients where the proximal landing zone of the endograft would be in zone 0 and no other option is available. The published data regarding this technique are still limited. Although the ideal choice for total endovascular repair might be a fenestrated/branched graft, the development of a custom-made device has long producing time. Therefore, it cannot be applied in emergency cases, making the triple-barrel technique the only available option for emergency endovascular aneurysm repair. The long-term follow-up remains to be evaluated with the increased number of patients treated.

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